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GUIDELINES FOR THE EVALUATION OF WATER
QUALITY FROM ANALYTICAL DATA

James M. Campbell, et al

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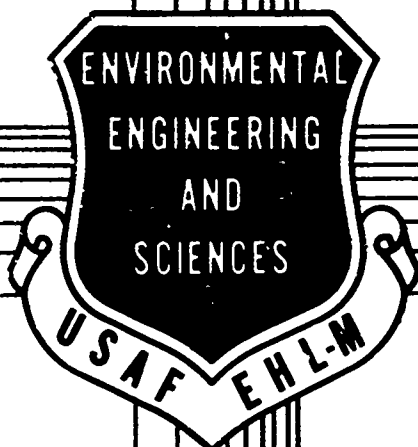
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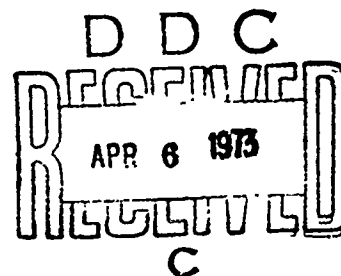
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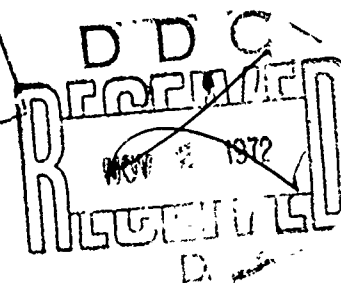
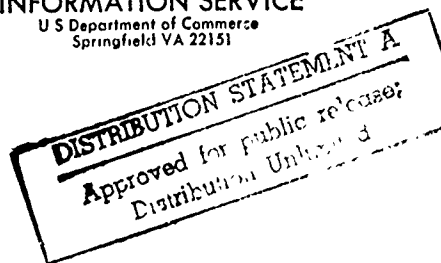
GUIDELINES FOR THE EVALUATION OF
WATER QUALITY FROM ANALYTICAL DATA

By

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and
Edward G. Robles, Jr.

September 1970

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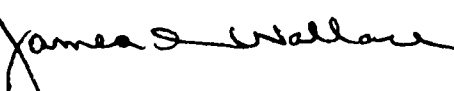
Prof. Report No. 70M-27
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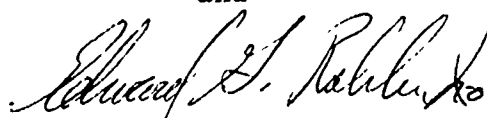
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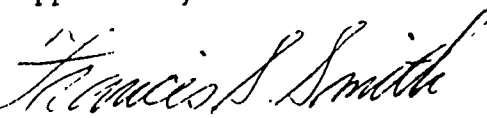
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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION	
USAF ENVIRONMENTAL HEALTH LABORATORY McClellan AFB, CA. 95652		Unclassified	
		2b. GROUP	
3. REPORT TITLE			
GUIDELINES FOR THE EVALUATION OF WATER QUALITY FROM ANALYTICAL DATA			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
FINAL			
5. AUTHOR(S) (First name, middle initial, last name)			
JAMES M. CAMPBELL EDWARD G. ROBLES, JR.			
6. REPORT DATE		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1970		2126	8
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO.		70M-27	
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. DISTRIBUTION STATEMENT			
Distribution of this document is unlimited			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
		USAF Environmental Health Lab McClellan AFB, CA 95652	
13. ABSTRACT			
<p>This paper covers, in laymen's terminology, the majority of currently applied water quality parameters. An understanding of these parameters will form the basic tools required for the evaluation of problems in water quality management.</p>			

DD FORM 1473
1 NOV 65

I-8

Unclassified

Security Classification

14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	WATER QUALITY WATER POLLUTION AIR FORCE EVALUATION OF WATER						

I-C

Unclassified

Security Classification

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SECTION I

PURPOSE

A. The intent of this report is to give the bio-environmental engineer, preventive medicine technician, or other personnel working in the field of water quality management a basic understanding of the parameters which are used to evaluate water quality.

B. While the discussion presented here is by no means complete, it should fulfill the intent of this presentation as outlined above. More information on the parameters discussed can be found in various references.

C. This understanding coupled with a meaningful water monitoring program should provide a basis for establishing a working water quality program.

D. Water in any state is virtually 100 percent H₂O. The classification as drinking water or waste water is only distinguishable through evaluation of the quality demanded or observed. Water will therefore be discussed here as an entity, with observations, where applicable, made as to its various qualities.

SECTION II

STANDARDS AND CRITERIA

A. References used in the interpretation of analytical reports on water samples use the terms "criteria" and "standards." The following is an interpretation of these terms:

1. Standards - This term applies to any definite rules, principles, or measures established by governmental authority. The key words in this definition are definite and established by authority. The fact that it has been established by authority makes a standard somewhat rigid, official, or quasi-legal; but this fact does not necessarily mean that the standard is fair, equitable, or based on sound scientific knowledge, for it may have been established somewhat arbitrarily on the basis of inadequate technical data tempered by a cautious factor of safety. Where health is involved and where scientific data are sparse, such arbitrary standards may be justified, at least on an interim basis.

2. Criteria - Criteria are scientific requirements on which decisions or judgments may be based concerning the suitability of

water quality to support a designated use. A criterion is a value to which a measurement is compared to form a judgment. Unlike a standard, it carries no connotation of authority other than that of fairness and equity; nor does it imply an ideal condition. When accumulated scientific data are being used to serve as yardsticks of water quality, without basis in legal authority, the term criteria is most applicable.

3. Types of Standards

a. Water Pollution Standards - There are two basic types of standards that have been used for control of water pollution. One type deals with the quality of the receiving water, whether stream, lake, river, estuary, open ocean, or ground water. This type is commonly designated as a "stream standard." The other type, referring to the quality of the wastes to be discharged from a given plant, is called an "effluent standard."

(1) Stream standards or standards of quality of the receiving water are based on threshold and limiting values for specific substances in the water, and they depend on the beneficial uses to which the water may be put. Widely used now and favored by those who feel that some sort of formalized criteria are necessary, stream standards are frequently correlated with a rigid system of stream classification or zoning whereby separate standards are set for each stream or zone. The principal advantage of standards of stream quality over effluent standards lies in the fact that they take into account dilution and the assimilative capacity of the receiving water, and consequently they lead to an economy of treatment works for pollution abatement. Stream standards, however, are more complex to formulate and define and much more difficult to administer than the effluent standards used by most regional, state, and local water pollution control agencies. A typical statement would require that "the dissolved oxygen shall not be caused to decrease to less than five milligrams per liter." The major disadvantage of stream standards is that treatment cost and efforts are not equitably divided between dischargers along the stream. A downstream user could be forced by circumstance to discharge only pure water.

(2) Effluent standards are divided into two broad categories; those that restrict the strength and/or the amount of substances that can be discharged and those that specify the degree of treatment or percentage removal of a specific pollutant that must be accomplished by treatment or by changes in industrial processes. Both of these

neglect the assimilative capacity of the stream. They can allow "legal" deterioration of the stream to other than satisfactory conditions. (See discussion under Biochemical Oxygen Demand.) The relative worth of each of these measures of pollution is a constant subject of conjecture.

b. Drinking Water Standards - These standards serve as minimum requirements for all public water supplies to protect the health and promote the well-being of individuals and of communities. The following two types of limits are used for chemical characteristics:

(1) Concentrations of substances which, if exceeded, are grounds for rejection of the supply. Substances in this category may have adverse effects on health when present in concentrations above the limit.

(2) Limits which should not be exceeded whenever more suitable supplies are, or can be made, available at reasonable cost. Substances in this category, when present in concentrations above the limit, are either objectionable to an appreciable number of people or exceed the levels required by good water quality control practices.

4. Types of Criteria - The following two types of criteria have been used in developing raw water criteria for public water supplies.

a. Permissible Criteria - These are characteristics and concentrations of substances in raw surface waters which will allow the production of a safe, clear, potable, aesthetically pleasing, and acceptable public water supply.

b. Desirable Criteria - Those characteristics and concentrations of substances in the raw surface waters which represent high quality water in all respects for use as public water supplies.

5. Development of Current Standards

a. The traditional uses of bodies of water, i. e., navigation, flood control, irrigation, and hydropower, with minor exception, consider only the quantity of water available. Similarly, waste transport or assimilation is usually based on quantity or some dilution factor. These uses were the original bases of water standards. Only after the quality of some water had deteriorated to an objectionable state did the need for more advanced standards become evident.

b. Standards based on uses of the water resource such as recreation, wildlife sustenance and flow augmentation, as well as municipal and industrial water supply have some basis in quantity but relate directly to quality. These apply primarily to the aesthetic quality and have gained much status in recent years.

c. Standards have, for the most part, been selected in an attempt to preserve streams for the greatest use, consistent with desires of the people. The Federal Water Pollution Control Act, amended by the Water Quality Improvement Act of 1970, authorizes the states to set quality standards for interstate waters. These standards must conform to or be more stringent than the requirements of similar standards approved by the Secretary of the Interior.

d. Standards have reached the place where they are treated as absolutes in most instances. This treatment belies the fact that standards may have been selected on a subjective basis. The limits might have been completely arbitrary or based on intimate knowledge of the basin, dischargers, and other factors. In most instances, shortcomings of the standards are being overcome by advances in technology and increased intensity of study. It is necessary, however, to comply, even though some hardships are created.

SECTION III

CONTROL PARAMETERS

A. GENERAL

1. Any observable phenomenon associated with water can be a tool in the maintenance of proper quality. These phenomena can be the physical condition, chemical constituents, biological usability, life forms existing in and around the water and the condition of the container or stream.

2. These phenomena or parameters can allow a fairly accurate appraisal of the water quality. Generally, these are divided into physical, chemical, and biological parameters, but as the text will show, there is significant overlapping in many cases.

3. Some typical criteria for evaluating water quality are presented as Attachment 1. These were originally collected by Dr. A. A. Bacher, FWQA.

B. PHYSICAL CONTROL PARAMETERS

1. Color - Pure water is colorless. Very clear bodies of water appear blue due to the refraction-reflection action of incident light. Color in water can be attributed to dissolved or suspended matter or to living organisms. For example:

a. Red, green, bluegreen, black, or purple varieties of algae and other organisms can impart their characteristic colors to a body of water. The "Red Tide" seen occasionally in the Gulf of Mexico is a similar occurrence. No other organisms have such abundance of color or sufficiently multitudinous populations to do this in large bodies of water. Filamentous iron bacteria growing in water lines can be a problem, giving tap water a red appearance.

b. Water in the Red River, carrying massive quantities of iron-laden clay in colloidal sizes gives rise to the river's name.

c. Many chemicals, both inorganic and organic, in molecular or ionic form, impart characteristic color to water. This true color, as differentiated from the apparent color from suspended solids, is normally not found in natural waters other than swamp water where tannin and leaf liquors give water a characteristic red-brown hue. Copper ion and chromate, examples of inorganics which give color, impart blue and yellow hues to a sample, respectively. Various organics, particularly those used as dyes, will give marked color at low concentrations. These cause the most problems in small streams used as receiving waters since the effect is greatly reduced by dilution. Removal of color is sometimes very difficult, and the aesthetic value of colored water is quite low. Color is measured in platinum-cobalt units and comparisons are made to serial standards prepared of potassium chloroplatinate (K_2PtCl_6) and cobalt chloride ($CoCl_2$). These standards resemble the color of natural water and are applied subjectively to other colors.

2. Odor - The threshold odor number of a sample is the number of dilutions by one-half with odor free water to make the odor of the sample just discernable. The requirement for low values of this parameter are obvious.

3. Turbidity - Turbidity is a measure of the ability of water to produce the extinction of a standard light source. This extinction

occurs through the absorption, backscattering, reflection, etc., of light by the material in the sample. The measurements are done by meters calibrated to read in Jackson Candle Units (JCU), the name coming from the original standard light source. Jackson Units (JU) or Jackson Turbidity Units (JTU) are equivalent. The turbidity of water is a measure only of its appearance since a small quantity of colloidal clay can make water just as turbid as a massive quantity of suspended sand or silt. This parameter is usually used to control backwashing cycles of rapid sand filters in water plants as it indicates failure of the filters in one of several ways.

4. Dissolved Oxygen (DO) - DO is the most often applied of the measures of control. Stream standards usually require a minimum of 4-5 milligrams per liter (mg/l) of DO in the stream. The level required is based on requirements for aquatic life and preservation of aerobic conditions throughout the stream. Depressions of DO level below a waste water outfall signifies the input of some type of oxygen demand. The oxygen sag curve or dissolved oxygen profile is a plot of DO versus time or distance downstream. The stream, through the mechanisms of mixing and diffusion, constantly tends to regenerate the DO to the saturation value, normally about 7 to 9 mg/l, dependent on temperature (Attachment 2). The relative rates of oxygen use by wastes and reaeration can give the oxygen sag curve for a specific stream or body of water for a specific set of conditions. Variables such as temperature, stream flow, channel shape, etc., make vast differences in the profile. Diurnal (day-to-night) variations may be noted. These are usually caused by large algae concentrations. Algal action, photosynthesis and respiration, respectively, can produce enough oxygen to drive a stream to 200 or 300 percent of normal saturation during the day or use enough to bring the level to 0 mg/l and anaerobic conditions at night. DO, therefore, is not an absolute measure of pollution by organic wastes but is a good indicator of receiving water quality.

5. Solids - In a water based liquid material, any matter except the water is considered as solids. Total solids (TS) are the residue left after evaporation of a sample and drying at 103 - 105°C. Some substances with substantial vapor pressure at this temperature range may be lost. Solids are often subdivided by one of several means. Examples of these are:

a. Volatile (VS) versus Fixed (FS) Solids - Combustion of a dried sample under controlled conditions converts organic materials

to carbon dioxide and water. Weight loss of the sample is volatile or organic, and the residue is called the fixed or inorganic solids. VS or volatile suspended solids (VSS) are valuable indicators in the operation of anaerobic digestors. Here these values are primarily indicators of the volatile acids present. Marked increase of VSS can show that the acid-forming bacteria are working faster than the methane forming bacteria which use the acids. Overproduction leads to a low pH which can kill the methane formers and thus upset the digester. Uncontrolled temperatures and a few unstable inorganics can introduce sizable errors in the determination of VSS.

b. Dissolved Versus Undissolved (or Suspended) Solids

(1) The different extremes of this classification are represented by potable hard water which has large amounts of dissolved solids and digester sludge where suspended solids are most prevalent. Potable water is limited to a maximum of 500 mg/l of dissolved solids, when possible, since higher concentrations often cause diarrhea or constipation in persons not adjusted to them. Low values of undissolved (or suspended) solids in sludges from waste water plants are often indicators of operation or process failure. Since dissolved solids are dissociated to the ionic or molecular level, Specific Conductance, the ability of the substance to carry a current, gives a quick indication of these materials. Undissolved solids are normally divided as to colloidal or settleable. These are important since sedimentation alone can remove the settleable solids while flocculation with chemicals and/or filtration is necessary for clarifying water containing colloidal particles.

(2) In sewage treatment, the physical process of sedimentation will normally remove 50 to 60 percent, by weight, of the undissolved solids. Conversion of dissolved solids by the bacterial population to either more bacteria or the by-products of carbon dioxide and water, gives an increase in settleable solids. The nature of these solids (roughly equivalent to the volatile suspended solids mentioned above) is such that they also can be removed by sedimentation. Entrapment of the remaining colloidal materials in the flocculating solids causes them to be removed to a level where other treatment is seldom necessary.

(3) In water treatment, surface sources usually have large amounts of colloidal material in suspension. Where the suspended material in sewage is primarily organic, natural waters have primarily

inorganic particles (silt and clay). Typically, the method of choice is chemical flocculation with an iron or aluminum salt (usually the sulfate) with pH adjustment followed by filtration.

6. Specific Conductance (See Dissolved Solids).

C. CHEMICAL CONTROL PARAMETERS

1. Biochemical Oxygen Demand (BOD) - (See subsequent paragraph D.1, Biological Control Parameters).

2. Chemical Oxygen Demand (COD) - COD, determined by oxidizing the organic material in a solution with strong oxidizing agents under very acid conditions, is the amount of oxygen required to convert the readily oxidizable organic content of a sample to carbon dioxide and water. Since this test converts virtually all organics, COD will normally be greater than BOD. In a sanitary waste, the difference would be small, while in a commercial waste such as wood pulping liquors, large amounts of non-degradable materials could cause a sizable variation. For a given organic compound such as glucose, the COD will exceed the BOD since some of the biological action includes conversion of organics to nondegradable cell materials while more complete oxidation occurs in the COD test. This test is widely used for waste treatment system control operations due to the short (3 hour) test completion time. BOD would be the preferred control parameter when secondary treatment is a bio-oxidation process and is used when possible, but the detection of rapid, short period fluctuations in the concentrations of organic matter requires a more rapid technique for adequate control.

3. Total Oxygen Demand (TOD) - TOD is an allied parameter which takes much less time to accomplish. Very small (usually twenty microliters) samples of a material are combusted at about 900°C in the presence of known quantities of oxygen. The oxygen used is a measure of the TOD. This value has been shown to be greater than COD. Some interfering substances may be present, but a major problem is obtaining a representative sample when suspended solids are present. Applications of this parameter is similar to that of COD or BOD.

4. Total Carbon - Total carbon content of a waste can be determined by the same method. In this case, however, oxygen is not metered; carbon dioxide in the flow stream indicates the total amount of carbon present. The problems are about the same as with the TOD analysis.

5. Nutrients - (See subsequent paragraph D.2., Biological Control Parameters.)

6. Surfactants - These substances are named for their surface active tendency. Due to the ability of their molecules to be dissolved in water at one end and not at the other, they form at the interfaces between air and water or oil and water. Here they can act as dissolvers or scrubbers. This surface active tendency puts large portions of the surfactant at the water-air interface allowing massive bubble and foam action. Infiltration of "hard" (non-degradable and/or slowly bio-degradable) surfactants into ground water has caused water supply contamination in many regions that will exist for long periods. Soaps and soft detergents are bio-degradable in secondary treatment processes.

7. Pesticides - This group contains those materials used for the control of all forms of pests. Sampling procedures for pesticides are outlined in Environmental Health Laboratory-McClellan Professional Report No. 69M-25 titled "Interim Report on Pilot Program for Pesticide Monitoring of Water on Air Force Bases," December 1969. This report specifies the problems of sampling, shipping, and analysis; it also provides some guidance on tolerance levels of pesticides in water. The desirable levels are, of course, zero.

8. Oils and Grease. Grease is the term applied to a variety of organics which are extracted from aqueous solution by hexane. Oils, fats, hydrocarbons, esters, waxes, and fatty acids with high molecular weight are included. The poor water solubility of these materials makes separation by flotation the best method where dissolution by detergents or emulsification of the oil has not occurred. When oil and grease are present in large percentages, approximations of content are made on volume percent with 1 percent equal to approximately 10,000 parts per million. It is significant that some persons sample for oil and grease by skimming the material from the surface; this invalidates any concentration figures given. Sample technique should always be noted along with the physical appearance characteristics of the water being sampled. Separation after sampling and emulsion breakdown are valid data for water pollution control. Due to the appearance, oil slicks are normally disallowed and undesirable.

9. pH and pHs - pH is the negative of the common logarithm of the molar concentration of hydrogen ions ($-\log_{10} H^+$) in a solution. The range of values is usually 0 to 14 with 7 representing neutrality. Values below 7 are acidic and above 7 are basic. This characteristic

of a solution gives an indication of its reactivity or corrosiveness. The pH of waters leaving a water treatment plant is adjusted to near the pH of stability (pH_s). This is the pH at which the water will neither corrode the equipment nor deposit scale at the temperature of release. This can be determined by formula $[pH_s = (pK_2 - pK_s) + pCa + pAlk]$ or by nomogram (Attachment 3). (Note: pCa or pAlk are the negative of the logarithm of the molar concentrations of calcium and alkalinity. Since formation of chemical floc and viability of micro-organisms are also dependent on pH, adjustment of the pH may occur several times in water or wastewater plants. Specific situations must be investigated to determine applicability of control. Most situations in sanitary engineering will, of course, require near neutrality of the water to allow bacterial viability (pH 6.5 - 8.0). Sludge digester failure often occurs when the pH is allowed to fall below about 6.5, killing the methane forming anaerobes.

10. Langlier (Saturation) Index - The Langlier (Saturation) Index (SI) is a measure of the corrosive or depositional nature of water. The SI is computed: $SI = pH - pH_s$. A negative SI indicates corrosive water and a positive value means the water will deposit scale. Water is normally kept at $SI = -0.2$ to avoid scale formation. Large deviations to the corrosive extreme can be very costly in equipment replacement and repair as well as problematical in other ways. Iron, manganese, and other metals eroded from the equipment can cause deposits in pipes, staining of fixtures and laundry as well as detracting from the aesthetic quality and safe nature of the water. The SI increases (more positive) with increases in temperature, necessitating additional controls for boilers, cooling towers, etc.

11. Solids - (See para B.5., Physical Control Parameters.)

12. Hardness - Hard waters are those which form scale (see Langlier Index) in water lines and boilers and which require large amounts of soap to form a lather. The economic implications of this problem are obvious. Total hardness (TH) is mainly caused by metallic divalent cations (Ca^{++} , Mg^{++} , Sr^{++} , Fe^{++} , Ba^{++} , Mn^{++}), principally those of calcium and magnesium. These cations form insoluble salts with soaps or such anions as carbonate, sulfate, phosphate, etc., (CO_3^{--} , SO_4^{--} , PO_4^{--} , SiO_3^{--}). Hardness is removed by chemical treatment and pH adjustment to form precipitates, which are removed by sedimentation or filtration. For taste control and soap lather formation and because of solubility characteristics, the hardness of water is

usually maintained between 75-100 mg/l.

a. For most waters, both calcium and magnesium ions contribute to the hardness. This is interpreted "as Calcium Carbonate" and is derived from the total number of equivalent weights of calcium and magnesium present per million parts of water, multiplied by the equivalent weight of Calcium Carbonate, or

$$TH = (\text{epm Ca} + \text{epm Mg}) \times 50.05$$

In this case, calcium and magnesium both being divalent cations, the equivalent weight is one half the atomic weight, and "epm" is derived by dividing "ppm" (or mg/l) by the equivalent weight.

b. Total Hardness is further divided into carbonate (temporary) hardness, and non-carbonate (permanent) hardness in the following manner.

$$\text{ppm non-carbonate hardness} = 50.05 (\text{epm Ca} + \text{epm Mg} - \text{epm alkalinity}).$$

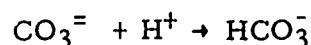
$$\text{ppm carbonate hardness} = \text{ppm total hardness} - \text{ppm non-carbonate hardness}.$$

Both types of hardness are important. Temporary (carbonate) hardness forms Calcium Carbonate scale upon boiling which is easily removed by acid-washing. Permanent (non-carbonate) hardness forms Calcium Sulfate or calcium and magnesium silicate scales which can be removed only by turbinizing, chipping, or other mechanical means.

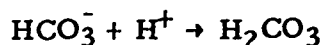
13. Alkalinity - This value is a measure of the ability of a water to neutralize acids or buffer the water. The alkalinity is the total of carbonate ($\text{CO}_3^{=}$), bicarbonate (HCO_3^-), and hydroxyl (OH^-), ions present with the salts of other weak acids, expressed as CaCO_3 . For most waters the OH^- will be zero. Determinations are made by titration with acid to two end points. If the initial pH > 8.2 the titration is done with phenolphthalein indicator to pH = 8.2. Hydroxyl ion (OH^-) converts to water and is nearly gone at pH \leq 12.3 by the reaction:



The reaction:



continues until pH = 8.2 when the CO_3^{--} is exhausted. This value of buffer capacity is called the phenolphthalein alkalinity. The second step is titration to pH = 4.5 with methyl orange as indicator:



The values obtained here are somewhat inexact and are of value primarily as indicators and for calculations of pHs, discussed under pH.

14. Acidity - This value is a measure of the ability of water to neutralize bases. It may occur as the result of the presence of carbon dioxide salts of heavy metals or organic or mineral acids which may be present. Titration with a base to the methyl orange and phenolphthalein endpoints discussed under alkalinity is the method of determination. This information is used to control the corrosive nature of ground water supplies. Industrial wastes with high mineral acidity must often be neutralized before entering treatment facilities or being discharged to streams.

15. Heavy Metals

a. Limits have been set upon these elements (USPHS Drinking Water Standards, 1962) in two ways: a lower limit, indicating that waters containing less than the indicated quantity are of no concern to the Public Health Official, and an upper limit, which may be used as grounds for prohibiting the use of a given water supply. These limits must be used with some caution; while it is true that waters exceeding the upper limits as set by the USPHS should not be utilized routinely, it is not true that such waters suddenly become poisonous when the upper limit is exceeded. The limits are set on the basis of daily usage of the water to the exclusion of other sources over a long period of time.

b. In the Western United States, many mineral springs containing large amounts of arsenic, lead, copper, etc., are to be found. These are definitely excluded as sources of potable water. However, most sources are usually free of such contaminants unless polluted from an outside source (industrial waste, mine effluents, etc.). In general, no effluent should be released which brings the receiving water above the lower USPHS limit for the heavy metals (arsenic, barium, cadmium, hexavalent chromium, copper, lead, mercury, selenium, silver, or zinc). Since local regulations may vary, the governing criteria must be established before discharging waste

waters containing "heavy metals." Of great concern to the ecology of the receiving water is the fact that certain heavy metals (notably copper and cadmium) are toxic to fish at much lower levels than they are tolerable by humans. Local regulations are frequently based on this fact.

c. Iron and manganese, not usually considered "heavy metals," are of limited physiological concern but are of vital importance in considering the esthetic quality of the water. Iron in excess of 0.5 ppm imparts an objectionable metallic taste to water; iron and manganese together in concentrations exceeding 0.3 ppm cause stains in laundry and on porcelain fixtures.

16. Common Cations - All natural waters contain greater or lesser amounts of the metallic ions (sodium, potassium, calcium, and magnesium). The latter two have been discussed under Hardness, above.

a. Sodium is not of great importance in potable water except in the case of persons having abnormal sodium metabolism. These persons are usually on salt-restricted diets, and it is quite important for the physician to be aware of the sodium content of the water for it may be necessary to require these persons to use distilled or demineralized water for a large portion of their drinking and cooking water. In other uses of water, however, sodium becomes of much greater importance. In boiler water, more than 50 ppm of sodium and potassium together may cause foaming and priming; in high pressure boilers, sodium should not exceed 2-3 ppm.

b. In agriculture, the relationship of the sodium to calcium and magnesium is important. Irrigation with water having a high sodium content may cause the dispersion of the soil colloids with a subsequent loss of soil permeability. It may also cause the formation of so-called "black alkali" soils which are difficult to till and impossible to gain adequate crop yield without massive additions of gypsum, dolomite, or other calcium-magnesium minerals. A useful parameter in this regard is the so-called sodium absorption ratio (SAR) which is computed as follows:

$$SAR = \frac{\text{epm Na}}{\sqrt{\frac{\text{epm Ca} + \text{epm Mg}}{2}}}$$

A high SAR would indicate that the water should not be used for irrigation.

17. Boron - Boron, as such, is slightly soluble in water. Its salts, the Borates, particularly Borax, are very soluble and are frequently used in detergents. In some areas of the United States it is found in concentrations as high as 5 to 15 mg/l. The element itself has low toxicity, but some of its compounds are moderately or highly toxic if ingested in large amounts. Boron can be an active poison to some plants. In irrigation use, as little as 1 ppm of boron can kill oranges and lemons, and 2 ppm will cause eventual difficulties with nearly all crops. The Public Health Service has established a limit of 1 mg/l which provides a good factor of safety physiologically and also considers the domestic use of water for home gardening.

18. Common Anions - All waters in normal use contain greater or lesser amounts of these ions (chloride, sulfate, nitrate, carbonate, and bicarbonate). The latter two are discussed under Alkalinity, above.

a. Chloride ion is essential to life and is an end-product of most metabolism. High chlorides and nitrates together in a water form an excellent index of suspected pollution by human or animal wastes. While chloride ion content of 1,000 ppm or more in the supply is probably safe, the USPHS recommends a limit of 250 ppm whenever possible. Chlorides in general contribute to the corrosive character of water; magnesium chloride in particular, upon heating, releases hydrochloric acid, thus lowering the pH to a corrosive level; hence, waters which are high in both magnesium and chloride will be expected to be more corrosive at high temperatures than the Saturation Index might indicate. Irrigation experience shows that high concentrations of chlorides may be toxic to plants.

b. Sulfate occurs in most natural waters and is an end point of sulfur metabolism for many bacteria. It may be extremely high in industrial effluents and mine wastes. In normal concentrations it is not very critical; however, water in excess of 1,000 ppm sulfate may be cathartic; it also imparts a pronounced "saline" flavor to the water. Epsom salts (magnesium sulfate) and Glauber's Salt (sodium sulfate) are commonly known saline cathartics. The USPHS suggests a limit of 250 ppm sulfate in potable water to prevent untoward effects.

c. Nitrate is the end product of aerobic decomposition of organic nitrogen compounds. Usually it is an important indication of

organic pollution of the water, particularly in conjunction with chloride; it may enter the water from irrigation return waters, having leached fertilizer from the soil. Levels above 10 ppm ordinarily suggest some form of pollution. Methemoglobinemia in infants may arise from feeding water containing more than 10-20 ppm of nitrate nitrogen. On this basis, the USPHS has suggested a reduction of the current limit for nitrate of 45 ppm. Nitrite, an associated metabolite of nitrogen, is usually absent in water containing dissolved oxygen since it is readily oxidized to nitrate. It is considered undesirable in potable water supplies. No limit has been set by the USPHS, but suggested limits varying from 0.1 ppm to 2 ppm have been proposed.

19. Phenols - Household or industrial wastes are sources of phenolic materials which can pollute water supplies. While not physiologically significant in quantities below 1.0 ppm, such a content is sufficiently offensive to the senses of taste and smell as to make the water undrinkable. Chlorinated phenols which may arise in water treatment processes are far more offensive; here the threshold of taste is 0.001 ppm. Concentrations up to 1,000 ppm would probably not be harmful to humans, but 5 ppm would probably be toxic to most fish. In practice, the upper limit of a discharge is ordinarily set at 0.02 ppm (20 ppb) for phenolic materials; since normal aerobic oxidation decomposes them rapidly and completely, very few problems may be expected from such wastes. The exception would be where a waste discharge directly enters the intake of a water treatment plant, as has occurred.

D. BIOLOGICAL CONTROL PARAMETERS

1. The Biochemical Oxygen Demand (BOD) is the amount of oxygen required by bacteria to stabilize a certain concentration of biodegradable organics. The BOD can be reported as ultimate BOD (BOD_u), 5-day BOD (BOD₅), first stage BOD₂₀, etc. Temperature of incubation, usually 20°C, is indicated: BOD₅²⁰. Normally, tests are run at or near stream conditions. A first stage or plateau may be reached when all BOD except that from nitrogenous materials is satisfied. Use rate will drop to very near zero at this time, then increase again before the final plateau or stage. The apparent value of this first plateau is the first stage BOD. BOD₅ is most used since it requires only five days to test completion, whereas others may go to extended periods. It is a good measure for fast acting, easily degradable organics, but can disguise massive amounts of slowly degraded materials which are detected by the ultimate BOD test. A typical value of BOD₅

for raw domestic sewage is 150 to 250 mg/l, while industrial wastes may go as high as 200,000 mg/l or more. A normal well-designed waste treatment plant, treating typical domestic waste, might remove 30-40 percent (60-80 mg/l) in the primary sedimentation unit and 70-90 percent of the remainder in the biological unit, giving an overall plant efficiency of 80-95 percent. Most plants are rated in this manner, and over 80 percent efficiency is usually considered adequate. Adequacy here does not mean that the stream is not being polluted. Effluent standards normally require BOD₅ reductions of 80-90 percent; or, stated another way, secondary treatment or the equivalent. These standards, properly applied, while they tend to equalize stress on the waste discharges, may or may not protect the stream. Improper application can allow misuse of the resource; e.g., a very small stream with zero BOD receiving waste from a large treatment plant could be overpowered and driven to an unsatisfactory condition. Eighty percent reduction of a typical waste could leave 40 mg/l of BOD₅ in the plant effluent. If plant and stream flows are equal, the stream will, after mixing, require 20 mg/l of oxygen to satisfy this BOD₅. Assuming a saturation value of 8 mg/l above the outfall and a stream standard of 5 mg/l minimum, 17 mg/l of oxygen entering from the atmosphere will be required to keep the DO above standard. This might not be possible. Formulas available in sanitary engineering texts allow rough estimates of stream effects. Perhaps the worst problem to be encountered in the use of DO and BOD as standards is that they can meet requirements while unsatisfactory stream conditions may exist. It is interesting to note that BOD can be indicated as zero if the waste is toxic to the indigenous or seeded micro-organism population. The only way to test BOD is to seed the sample with micro-organisms and measure the amount of oxygen consumed. This is normally done by base personnel since delays invalidate the test and preservatives would not allow reseeded.

2. Nutrients - Nutrients are those minerals (primarily nitrogen and phosphorous) which are required to support micro-organism growth. They are important in waters where microbial growth is of concern. Nutrients must be present in sewage lagoons to promote the algal growth necessary to prevent anaerobic conditions and the accompanying unpleasant odors. Domestic waste, high in nutrients, is usually added to industrial waste treatment when biological treatment is being used to assure the required levels of nutrients. Algal blooms are one of the first signs of the advanced pollution of bodies of water. Algae, with only nutrients and sunlight as an energy source, reproduce in characteristic fashion to form slimes, floating mats and cause other objectionable conditions. Since they are esthetically undesirable and

readily apparent, nutrient input is of great concern.

16. Living Organisms - Life forms, or the lack thereof, in water can be a valuable indication of quality. The coliform organism, *Escherichia coli*, is used as an indicator for biological quality of drinking water. Hardier than, and more abundant in human feces than *Salmonella typhosa*, the causative agent of typhoid fever, reduction of *E. coli* to less than appropriate criteria virtually guarantees extinction of any existing *S. typhosa*. Currently, some investigators are suggesting a change to *Streptococcus faecalis* as an indicator, but data are insufficient to warrant the change. Life in an unpolluted stream or lake usually consists of a wide range of species with the total numbers somewhat limited, while vast multitudes of relatively few species inhabit the polluted waters. Bottom accumulations can wipe out many species while providing abundant food for a few species which can propagate to phenomenal numbers. Overabundance of nutrients can cause massive algal blooms and subsequent rises in populations of the algae-eaters to the virtual exclusion of other species.

SECTION IV

SUGGESTED LIBRARY

The following basic references should be part of the Aerospace Medicine Program's library for interpreting analytical reports on water samples:

1. AFM 160-4 dated 17 December 1957 and -4A dated 2 April 1958, "Sanitary Control of Water Supplies for Fixed Installations."
2. Public Health Service Publication No. 956, Drinking Water Standards, Dept. of Health, Education, and Welfare, 1962.
3. Report of the Committee on Water Quality Criteria, Fed Wat Poll Cont Adm., U. S. Dept of the Interior, 1968.
4. AFP 161-20 dated 14 Aug 1969, "Water Pollution."
5. Sawyer, Clair N. and McCarty, Perry L., Chemistry for Sanitary Engineers, 2nd Ed., McGraw Hill, 1967.
6. APHA, AWWA, WPCF, "Standard Methods for the Examination of Water and Wastewater," 12th ed., Amer. Pub. Health Assoc., Inc., 1966.

SECTION V

REFERENCES

1. AFM 160-4 dated 17 December 1957 and -4A dated 2 April 1958, "Sanitary Control of Water Supplies for Fixed Installations."
2. AFP 161-20 dated 14 Aug 1969, "Water Pollution."
3. Public Health Service Publication No. 956, Drinking Water Standards, Dept of Health, Education, and Welfare, 1962.
4. Report of the Committee on Water Quality Criteria, Fed Wat Poll Cont Adm., U.S. Dept of the Interior, 1968.
5. Sawyer, Clair N. and McCarty, Perry L., Chemistry for Sanitary Engineers, 2nd Ed, McGraw Hill, 1967.
6. Riehl, Merrill L., Water, Supply and Treatment, 9th Ed., National Lime Assn., 1962.
7. Pomeroy, R. and Orlob, G. T., Problems of Setting Standards and of Surveillance for Water Quality Control, prepared for SWQCB, January 1967.
8. McKee, J. E. and Wolf, H. W., Water Quality Criteria, SWQCB Publication 3-A, 1963.

Note: These references or the equivalent are recommended as valuable additions to the library of Air Force personnel who are involved in water and the pollution problem.

RANGES OF VALUES FOR EFFLUENT QUALITY TO BE USED IN THE DEVELOPMENT OF WASTE WATER TREATMENT PROCESSES

(These values are for planning of waste treatment projects only and do not represent optimum,
desirable, mandatory, or permissible limits of the parameters whose values are given.)

Constituent or Measurement	Desirable Level (for Public Water Supply)			Permissible Level (Surface Water for Public Water Supply)		Alternative Uses			
	Detectable Limit	2 Units	3 Units	15 Units	Body Contact (Recreation)	Fisheries Use	Farmstead Supply	Irrigation Uses	Industrial Uses
Turbidity	0.1 JTU	0.1 JTU	0.1 JTU	30.0 JTU	25.0 JTU	25.0 JTU	25.0 JTU		
Color	2 Units	3 Units	3 Units	15 Units			20 Units		
Odor (At 25°C.)	0 Threshold	0 Threshold	0 Threshold						
pH	0.1	7.0-8.5	7.0-8.5	6.0-8.5	6.5-8.3	6.5-9.0	6.0-8.5		3.5-9.1
Total Residue	1.0 mg/l	500.0 mg/l	500.0 mg/l	1000.0 mg/l					
Filtrable Residue	1.0 mg/l	200.0 mg/l	500.0 mg/l	500.0 mg/l					
BOD	0.5 mg/l	2.0 mg/l	4.0 mg/l	4.0 mg/l				100.0 mg/l	
TOC	1.0 mg/l	5.0 mg/l	10.0 mg/l	10.0 mg/l					
CCE	0.001 mg/l	0.04 mg/l	0.1 mg/l	0.1 mg/l					100 mg/l
MBAS	0.05 mg/l	<0.25 mg/l	0.5 mg/l	0.5 mg/l					1.3 mg/l
Alkalinity	1.0 mg/l	250.0 mg/l	400.0 mg/l	400.0 mg/l					500.0 mg/l
Aluminum	0.01 mg/l	0.05 mg/l	0.1 mg/l	0.1 mg/l				1.0 mg/l	3.0 mg/l
Ammonia as N	0.005 mg/l	0.01 mg/l	0.05 mg/l	0.05 mg/l	1.0 mg/l	1.0 mg/l			
Arsenic	0.01 mg/l	0.01 mg/l	0.05 mg/l	0.05 mg/l			<0.05 mg/l		0.1 mg/l
Barium	0.4 mg/l	0.5 mg/l	1.0 mg/l	1.0 mg/l			1.0 mg/l		2.0 mg/l
Boron	0.02 mg/l	0.025 mg/l	1.0 mg/l	1.0 mg/l				0.75 mg/l	
Cadmium	0.001 mg/l	0.005 mg/l	0.01 mg/l	0.01 mg/l			0.01 mg/l	0.005 mg/l	0.02 mg/l
Chloride	1.0 mg/l	<25.0 mg/l	250.0 mg/l	250.0 mg/l		50.0 mg/l			500.0 mg/l
Chromium (hexavalent)	0.01 mg/l	0.02 mg/l	0.05 mg/l	0.05 mg/l	1.0 mg/l	1.0 mg/l	0.05 mg/l	5.0 mg/l	0.1 mg/l
Copper	0.004 mg/l	<0.01 mg/l	0.2 mg/l	0.2 mg/l	0.2 mg/l	0.2 mg/l	1.0 mg/l	0.2 mg/l	0.4 mg/l
Dissolved Oxygen	0.1 mg/l	8.0 mg/l	<5.0 mg/l	<5.0 mg/l	5.0 mg/l	7.0 mg/l			
Fluoride	0.1 mg/l	1.0 mg/l	1.2 mg/l	1.2 mg/l			1.2 mg/l		3.0 mg/l
Hardness as CaCo	1.0 mg/l	80.0 ¹ mg/l	250.0 ¹ mg/l	250.0 ¹ mg/l					
Calcium	0.1 mg/l	15.0 ¹ mg/l	43.0 ¹ mg/l	43.0 ¹ mg/l					
Magnesium	0.1 mg/l	10.0 ¹ mg/l	29.0 ¹ mg/l	29.0 ¹ mg/l					
Iron	0.005 mg/l	0.05 mg/l	0.1 mg/l	0.1 mg/l			0.3 mg/l		0.6 mg/l
Lead	0.01 mg/l	0.01 mg/l	0.05 mg/l	0.05 mg/l			0.05 mg/l		0.1 mg/l
Manganese	0.001 mg/l	0.01 mg/l	0.05 mg/l	0.05 mg/l			0.05 mg/l	2.0 mg/l	0.6 mg/l
Nitrates & Nitrites as N	0.1 mg/l	0.1 mg/l	2.0-4.0 mg/l	0.1 mg/l			45.0 mg/l		20.0 mg/l
Phosphorus	0.01 mg/l	0.01 mg/l	0.1 mg/l	0.1 mg/l					4.0 mg/l
Selenium	0.004 mg/l	<0.01 mg/l	0.01 mg/l	0.01 mg/l			0.01 mg/l		0.2 mg/l
Silver	0.001 mg/l	0.001 mg/l	0.05 mg/l	0.05 mg/l					0.1 mg/l
Sulfate	1.0 mg/l	50.0 mg/l	250.0 mg/l	250.0 mg/l					680.0 mg/l
Total Dissolved Solids	1.0 mg/l	200.0 mg/l	<500.0 mg/l	<500.0 mg/l	500.0 mg/l	240.0 mg/l			1000.0 mg/l
Uranium Ion	0.005 mg/l	<0.5 mg/l	5.0 mg/l	5.0 mg/l			5.0 mg/l	5.0 mg/l	0.6 mg/l
Zinc	0.001 mg/l	0.05 mg/l	5.0 mg/l	5.0 mg/l					0.4 mg/l
Cyanide	0.005 mg/l	0.01 mg/l	0.1 mg/l	0.1 mg/l	0.02 mg/l	0.02 mg/l	0.02		
Oil & Grease	<0.05 mg/l	<0.05 mg/l	0.05 mg/l	0.05 mg/l					
INSECTICIDES ^{2,3}									
Aldrin		<0.05 µg/l	<1.7 µg/l	<0.05 µg/l	<0.05 µg/l	<0.05 µg/l	<1.7 µg/l	<1.7 µg/l	<0.05 µg/l
Chlordane		<0.02 µg/l	<0.3 µg/l	<0.02 µg/l	<0.02 µg/l	<0.02 µg/l	<0.3 µg/l	<0.3 µg/l	<0.02 µg/l
DDT		<0.006 µg/l	<4.2 µg/l	<0.006 µg/l	<0.006 µg/l	<0.006 µg/l	<4.2 µg/l	<4.2 µg/l	<0.006 µg/l
Dieldrin		<0.003 µg/l	<1.7 µg/l	<0.003 µg/l	<0.003 µg/l	<0.003 µg/l	<1.7 µg/l	<1.7 µg/l	<0.003 µg/l
Endrin		<0.002 µg/l	<0.1 µg/l	<0.002 µg/l	<0.002 µg/l	<0.002 µg/l	<0.1 µg/l	<0.1 µg/l	<0.002 µg/l
Heptachlor		<0.002 µg/l	<1.8 µg/l	<0.002 µg/l	<0.002 µg/l	<0.002 µg/l	<1.8 µg/l	<1.8 µg/l	<0.002 µg/l
Heptachlor epoxide		<0.0002 µg/l	<1.8 µg/l	<0.0002 µg/l	<0.0002 µg/l	<0.0002 µg/l	<1.8 µg/l	<1.8 µg/l	<0.0002 µg/l
Lindane		<0.002 µg/l	<5.6 µg/l	<0.002 µg/l	<0.002 µg/l	<0.002 µg/l	<5.6 µg/l	<5.6 µg/l	<0.002 µg/l
Methoxychlor		<0.004 µg/l	<3.5 µg/l	<0.004 µg/l	<0.004 µg/l	<0.004 µg/l	<3.5 µg/l	<3.5 µg/l	<0.004 µg/l
Organic Phosphates plus Carbamates		<0.0003 µg/l	<10.0 µg/l	<0.0003 µg/l	<0.0003 µg/l	<0.0003 µg/l	<10.0 µg/l	<10.0 µg/l	<0.0003 µg/l
Toxaphene		<0.03 µg/l	<0.5 µg/l	<0.03 µg/l	<0.03 µg/l	<0.03 µg/l	<0.5 µg/l	<0.5 µg/l	<0.03 µg/l
HERBICIDES ³									
2,4-D plus 2,4,5-T plus 2,4,5-TP		10.0 µg/l	10.0 µg/l	10.0 µg/l	10.0 µg/l	10.0 µg/l	10.0 µg/l	2.0 µg/l	10.0 µg/l
Phenols	0.0005 mg/l	0.001 mg/l	0.005 mg/l	0.001 mg/l	0.01 mg/l	0.01 mg/l			0.002 mg/l
RADIOACTIVITY ⁴									
Gross Beta	1.0 pc/l	100.0 pc/l	1000.0 pc/l	1000.0 pc/l	1000.0 pc/l	1000.0 pc/l	1000.0 pc/l	1000.0 pc/l	1000.0 pc/l
Radium-226	0.05 pc/l	<1.0 pc/l	3.0 pc/l	3.0 pc/l	3.0 pc/l	3.0 pc/l	3.0 pc/l	3.0 pc/l	3.0 pc/l
Strontium-90	3.05 pc/l	<2.0 pc/l	10.0 pc/l	10.0 pc/l	10.0 pc/l	10.0 pc/l	10.0 pc/l	10.0 pc/l	10.0 pc/l
MICROBIOLOGICAL									
Coliform		100/100 ml	10,000/100 ml	1000/100 ml	1000/100 ml	5,000/100 ml	5,000/100 ml	5,000/100 ml	10,000/100 ml
Fecal Coliform		20/100 ml	2,000/100 ml	200/100 ml	200/100 ml	1,000/100 ml	1,000/100 ml	1,000/100 ml	2,000/100 ml

¹ The values for hardness, calcium and magnesium have been determined from averages. A 3:2 ratio has been decided upon for calcium and magnesium (private communication from U.S.G.S.)

² The Limits given under permissible level are the ones given in the report on Water Quality Criteria, but will have to be lowered in the future, according to information obtained from Dr. Mount, "U.S. Department of the Interior, FWPCA, National Water Quality Laboratory."

³ Detectable limit for Insecticides and Herbicides is within 10⁻⁶ µg per liter.

⁴ Permissible and Desirable levels only in the absence of 90 Br, 129 I, 210 Pb, 210 Po, 211 At, 223 Ra, 224 Ra, 226 Ra, 230 Th, 231 Pa, 232 Th and Thorium (natural or only when it has been established that 90 Br content is <10 pc/l and in the absence of alpha-limiting radionuclides (Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure, Handbook 69, U.S. Department of Commerce, National Bureau of Standards.)

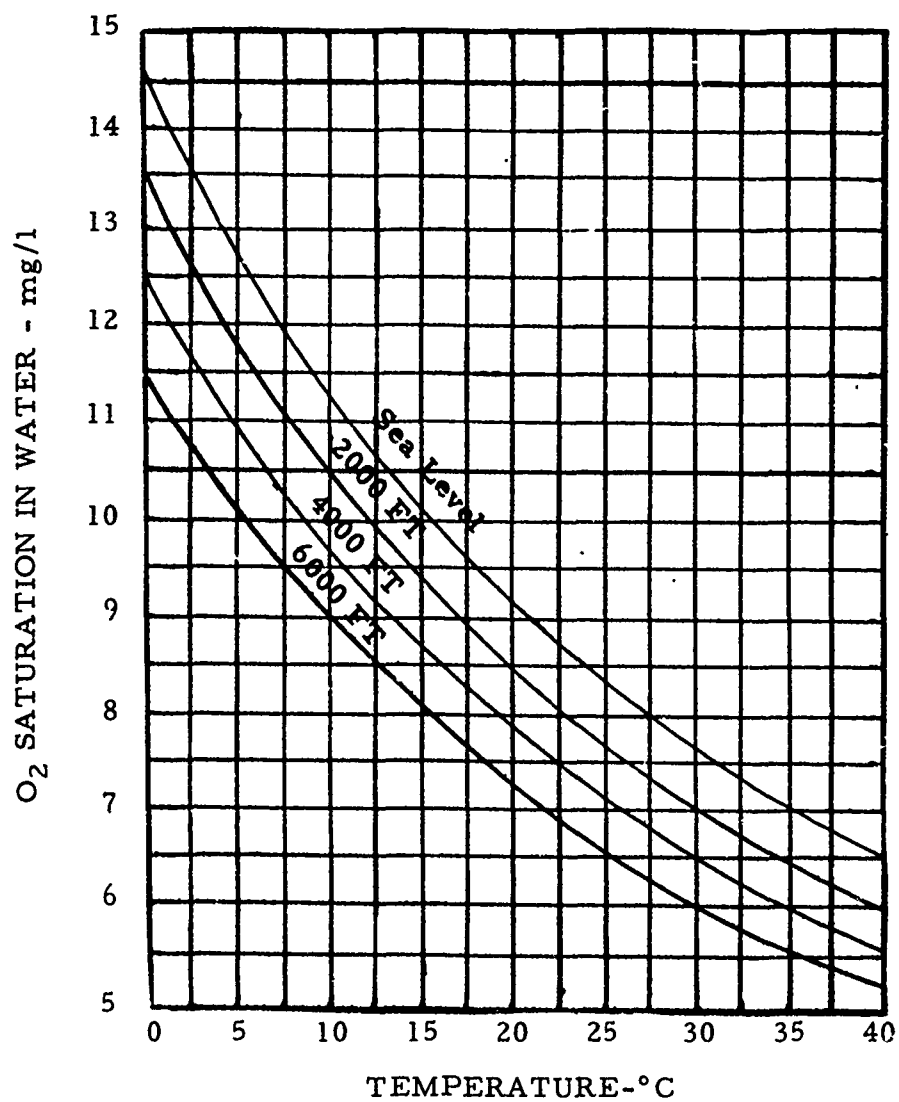
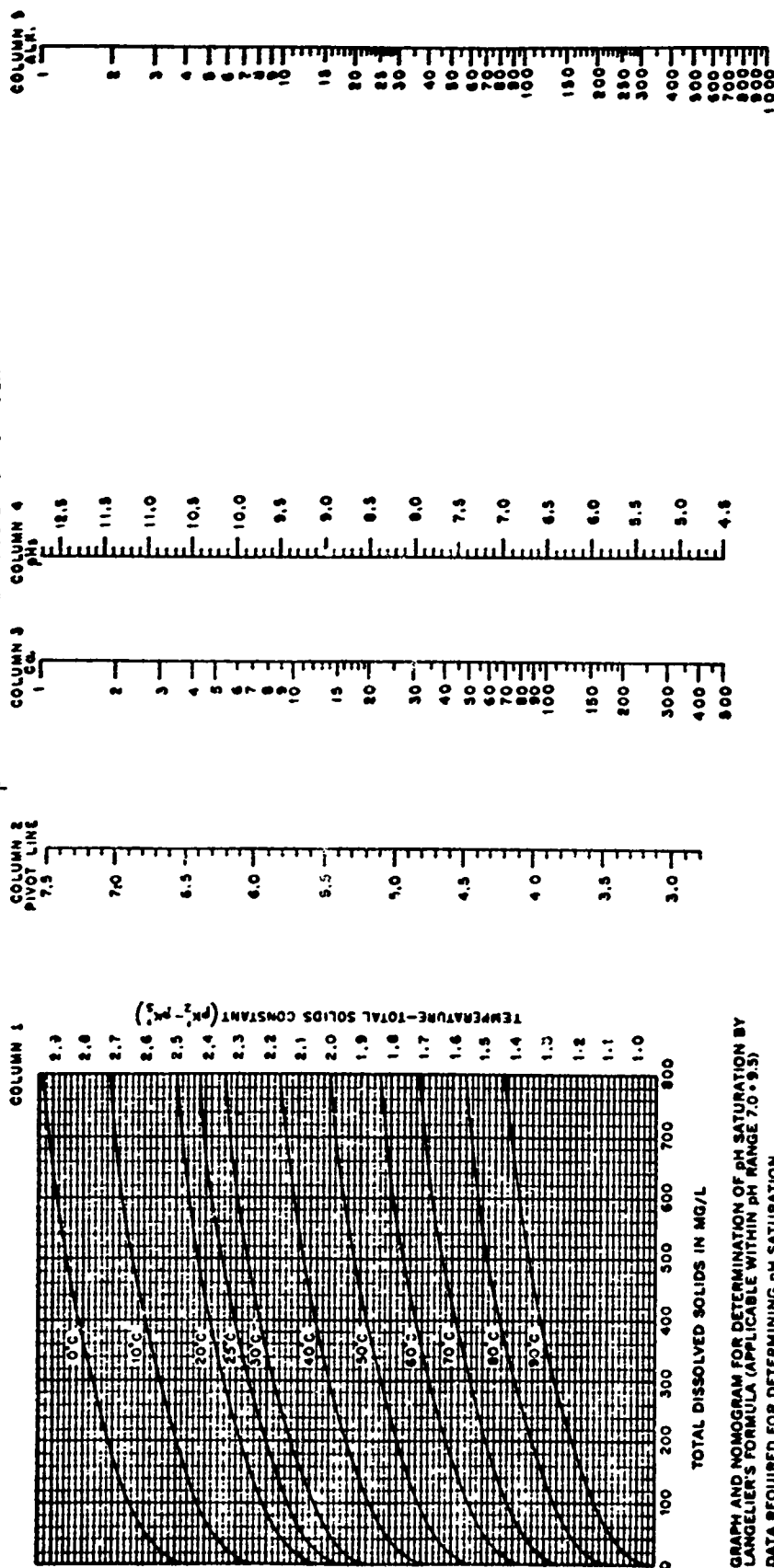


Figure 1-2. Solubility of Oxygen in Fresh Water

GRAPH AND NOMOGRAM FOR DETERMINATION OF pH SATURATION BY LANGELETT'S FORMULA



GRAPH AND NOMOGRAM FOR DETERMINATION OF pH SATURATION BY LANGELETT'S FORMULA (APPLICABLE WITHIN pH RANGE 7.0-9.5)

DATA REQUIRED FOR DETERMINING pH SATURATION

(A) TOTAL ALKALINITY, AS MG/L OF CaCO_3

(B) TOTAL DISSOLVED SOLIDS, IN MG/L

(C) TEMPERATURE IN DEGREES CENTIGRADE, AT WHICH pH SATURATION IS DESIRED.

INSTRUCTIONS FOR USING CHART

(1) ALIGN TOTAL DISSOLVED SOLIDS, FIND TEMPERATURE & TOTAL SOLIDS CONSTANT ON COL. 1.

(2) ALIGN THIS CONSTANT WITH GIVEN ALKALINITY ON COL. 2 OF CHART (PIVOT LINE).

(3) ALIGN THIS POINT ON PIVOT LINE WITH GIVEN ALKALINITY ON COL. 3 OF CHART.

SATURATION INDEX IS pH ACTUAL MINUS pH SATURATION. E.G. - pH ACTUAL pH SATURATION, SATURATION INDEX

8.1 - 7.8 = +0.3 (CORROSIVE)

8.1 - 7.5 = +0.6 (SCALE FORMING)

GRAPH AND NOMOGRAM FOR DETERMINATION OF pH SATURATION AND LANGELETT'S SATURATION INDEX BASED ON ARTICLE IN OCT. 1936, ISSUE OF AMERICAN WATER WORKS ASSOCIATION JOURNAL AND LATER CORRECTIONS FOR TABLE 2 AND 4, PREPARED FOR CHARLES P. HOOVER OF THE COLUMBUS, OHIO, WATER SOFTENING AND PURIFICATION PLANT BY MERRILL L. NIEHL

SEPT. 17, 1938

LANGELETT'S FORMULA